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The Light – an integrated approach to the phenomenon

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Abstract

Phenomena and natural processes have an integrated character. Interpretation and solving of simple or complicated problems related to natural phenomena involve recourse to knowledge, skills and competencies. They may not be framed purely in the context of a single discipline.
Contemporary scientific world challenge lies in the ability to make quick and efficient interdisciplinary transfers, in synthesizing knowledge, skills and expertise gained by studying various disciplines. In this context, the light, as concept and phenomenon is analyzed in terms of natural sciences. Discipline like as Physics, Chemistry and Biology meeting on the level where they give an integrated approach of the light.

Keywords: Integrate teaching, light, concept, natural phenomenon, transdisciplinarity;

1. Introduction

We are proposing to organize and inter relate the different school disciplines with the aim of avoiding their traditional isolation (Miron, 2008). By doing so we hope to develop the connections between what students learn and their past and present experience. Monodisciplinarity, multidisciplinarity, interdisciplinarity and transdisciplinarity are the levels of integral approach of the curriculum (Bocos, 2001).

While monodisciplinarity proposes the scientifical study of a single domain, in the multidisciplinarity the subject of the phenomenon is analyzed according with a cumulated knowledge from many fields of study. This kind of approach can ultimately lead to the fusion of different subjects of study (Cristea, 2000).

In this study we focus on the notion of light as a natural phenomenon. We are approaching this subject using knowledge from Physics, Chemistry and Biology to explain its origins and how light interact with matter (Ilisie, Barna, & Chitu, 2010).

The reason of this approach is that we believe that a clear separation in explaining a phenomenon based on only one discipline of study is not appropriate in the complex world that we are living on today (Cretu, 1998).

As a result, we consider that this approach is preferable as opposed to the traditional ways of learning in the present and the future (Vlada, Albeanu, & Popovici, 2010).

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2. Light as a notion and phenomenon

What is light? People have asked this question from time immemorial, and their answer was related with their degree of understanding and knowledge.

Pitagora, for example, believed that the objects can be seen because they emit certain particles that strike the human eye. Descartes perceived light as a perturbation that propagates in a perfect elastic medium that fills the entire space. Hooke (1635-1703) thought that the light is composed of compressed things that are propagating very fast. The Czech monk called Marci (1595-1667) and the Italian monk, Grimaldi (1618-1663) reached the conclusion that light is a very fast traveling wave. Its speed was estimated for the first time as being 215000 km/s by the Dutch Olaf Romer, by observing the periodical eclipse of the Jupiter satellites. More precise estimates were made later by Foucault, by using the method of rotating mirrors, and the value obtained was 298 000 km/s. Michelson, using rotating prism method, obtained value of 299 796 km / s for the speed of light. The current accepted value for the speed of light in vacuum is c=299 792.456 km/s which is approximated by 300 000 Km/s.

In the famous physics publication called “Optics treaty” from 1704, Newton reached the conclusion that light is made of particles emitted by objects. Thus, the linear propagation of light is reduced to the law of inertia. The corpuscular theory explains the reflection and the refraction of light taking into consideration certain forces between the optical media that interact with the light particles at this specific interface. According with Newton’s theory, the speed of light should be higher if the light interacts more with the media in which it travels.

On the other hand, according with the wave theory, the light is a vibratory phenomenon that propagates through elastic waves in a medium that surrounds us and the universe. To explain the linear propagation of light Huygens introduced a principle that bears his name. According to it, the perturbation present at a certain point can be considered as a superposition of secondary waves (that were considered later by Fresnel as being coherent in nature) that were emitted in each point from a wave surface. Thus, light is a longitudinal wave that propagates in vacuum similar with the propagation of sound in air. Huygens explains the reflection and the refraction of light and reached a contrary conclusion from Newton regarding the speed of propagation through media: it travels faster if there is less interaction with media. None of these theories could explain the phenomenon of diffraction of light, observed first by Grimaldi and later, independently, by Hooke.

At the beginning of 19th century the balance started to tilt in the favor of the wave theory due to systematic research by Young (1773-1829) and Fresnel (1788-1827). With this new theory discovered, phenomena such as: the polarization of light through reflection (Malus, 1808) and refraction (Malus and Biot, 1801), the angle of total polarization (Brewster, 1815), the interference of polarized beams (Fresnel and Arago, 1816), birefringence (Brewster, 1815) could be easily explained.

In 1807 Young measured the wavelength of light. Young noted that the red rays have a greater wavelength than the violet rays, and thus establishes the link between colour and wavelength of the light.

In 1817 Young established a theory that considers light waves as being transversal. Four years later Fresnel confirmed it by studying the polarization and interference of light (Sivoukhine, 1984).

Around the middle of 19th century James Clerk Maxwell succeeded to unify the electrical and magnetic theories calling it the “electromagnetic field theory”. The presence of electrical charges in the medium produces an excited state named electromagnetic field characterized by the vectors **E -** the intensity of electric field, and **H -** the intensity of the magnetic field. The presence of substance that fills the medium leads to the introduction of different notions such as: current density **J**, electrical **D** induction, and magnetic **D** induction. These vectors are interrelated in time and position through Maxwell’s equations. These equations, for a continuum media, have the following form:

$$(1)\quad \nabla \times \vec{H} = \vec{J} + \frac{\partial \vec{D}}{\partial t}$$

$$(2)\quad \nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$$

(3) $\nabla \cdot \vec{D} = \rho$

(4) $\nabla \cdot \vec{B} = 0$,

ρ represents the density of electrical charge in the specific media.
The equations relative to the material give its characteristics:

(5) $\vec{J} = \sigma \vec{E}$

(6) $\vec{D} = \varepsilon \vec{E}$

(7) $\vec{B} = \mu \vec{H}$,

σ is the electrical conductivity, ε is the electrical permittivity and μ is the magnetic permeability of the medium. Also, c is the report between the electromagnetic and electrostatic units of current intensity (this is exactly the light speed in vacuum) (Bratescu, 1982). From Maxwell equations, the vectors E and H are perpendicular on each other and also give us the propagation direction. Moreover, it demonstrates that this electromagnetic field propagates in vacuum as electromagnetic waves with the velocity c=1/√ε0μ0, which is the speed of light. This fact, the transversal character of electromagnetic waves, led Maxwell to conclude that the light is an electromagnetic wave. In this way, the optics became part of treatment of the electromagnetic theory.

The electromagnetic waves have a wide frequency range, theoretically unlimited. Visible light takes a narrow portion from this large spectrum, having the wavelength between 400 and 750 nm. The electromagnetic theory of light was not complete. It cannot explain the way that incandescent bodies emitting light and their energy distribution according with the light wavelength. Also, it cannot explain the phenomenon connected with the interaction between light and matter. These phenomena could be explained by using the quantum theory of light formulated in 1900 by the German scientist Marx Plank. He introduced a revolutionary concept that the microscopic oscillators (atoms) emit and absorb the electromagnetic light in a discontinued manner, in portions and finite packets, which he called energetic quant. The value of this quant is given by formula:

(8) $\varepsilon = h\nu$,

Here h =6.626 · 10-34 J·s is the Planck's constant and ν is the frequency of the emitted or absorbed radiation.

Five years later, Einstein showed that this idea can also be applied in the case of light, whose propagation in space is made through energy packages or light quanta, having the energy ε=hν and the momentum p=h/λ, well defined. Thus, the corpuscular theory and the concept of light particle (which was called later, in 1926, photon by Gilbert Newton Lewis) were brought back to life. The photons hypothesis allowed the explanation of the photoelectric effect (emission of electrons by the metals being under light irradiation) and its laws (Einstein, 1905). Also, it was elucidated the Compton Effect (wavelength variation of scattered X-rays). These phenomena couldn't be understood inside the wave theory of light. Moreover, this hypothesis permitted to explain the nature of light chemical interactions and to establish their laws.

Niels Bohr used the concept of light quantum to discover the laws that rule the emission and the absorption spectra of the atoms. It was necessary to admit that light particles obey to other laws of physics than the classic mechanics ones that are the laws of quantum physics. In conclusion, the phenomena that accompany the propagation of light (interference, diffraction, polarization) are correctly explained by the wave theory of light, while the phenomena of light interaction with substance (photoelectric effect, Compton Effect) are perfectly described by the corpuscular theory of light. This wave-particle duality (double nature) has to be considered as an experimental fact and, consequently, any exhaustive theory about light can't be neither corpuscular, nor optic light wave theory, but a mixed one, corpuscular and optic light wave theory.

At the end of the 19th century, has become the hypothesis that electromagnetic radiation, light in particular, is emitted within the atoms. Atoms or molecules can be brought to the condition of emitting light by electric discharges in gases, by striking them with thermo electrons, by heating the substance in a gas flame or by lighting with other radiations. The radiations emitted by atoms reveal themselves by the appearance of some spectral series composed of spectral lines with different intensities. Each line corresponds to a monochromatic radiation emitted by the source, having well defined values for its frequency or wavelength. All these lines form the spectrum of the substance. The spectroscopy studies showed that each chemical element emits and absorbs a characteristic group of lines which allows the element identification.

Studying the lines spectrum of hydrogen in the visible area, Johann Balmer (1825-1898) and Johannes Rydberg (1854-1919) learned that the wavelengths of the emitted radiations are linked together by an empirical formula (Bratescu, 1982):

$$(9) \quad \frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{n^2}\right)$$

R=1.097373 · 107 m-1 is the Rydberg constant and n takes the integer values 3, 4, 5… The spectral lines which answer to this formula form a spectral series, called the Balmer series. Later, other spectral series of hydrogen atom, placed in ultraviolet and infrared area (the Lyman, Paschen, Brackett, Pfund and Humphrey series) were discovered.

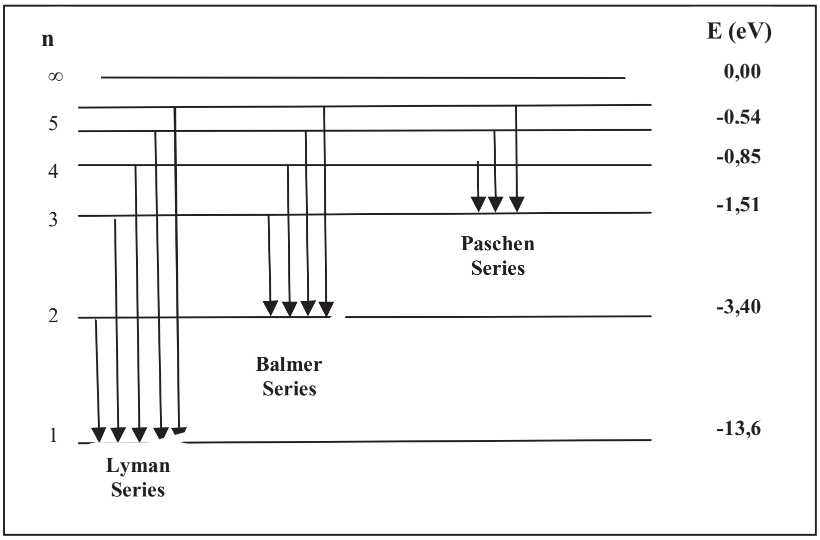

Figure 1.The diagram of the spectral series at the hydrogen atom

A further step in establishing the internal structure of the atom was made by Niels Bohr (1885-1962) which showed that the classic physics laws are not valid at atomic scale. The behavior of atoms is governed by the quantum physics laws. He revealed the essence of this behavior in his famous postulates.

Bohr pointed out that the normal state of an atom is the fundamental state. As a result of the interactions with the exterior environment, an atom can temporary get enough energy to pass to a higher energy state (or an excited state). In the process of de- excitation the atom emits a photon with well defined energy, corresponding to that quantum transition. According to Bohr postulates, the spectral series of hydrogen atom has a simple interpretation: the lines of a given series appear from the atom's transitions in which the final level of energy is fixed and the initials levels are, in turns, all the superior energy levels (figure 1).

At the thermodynamic equilibrium the population on the energetic levels decreases with their increase in energy, according with the relationship (Bunget, 1988):

$$(10) \quad N_2 = N_1 e^{-\frac{E_2 - E_1}{kT}} = N_1 e^{-\frac{h\nu}{kT}}$$

N1 and N2 represent the number of excited atoms on the energetic levels E1 , E2; k is the Boltzman constant (1844-1906), and T is the absolute temperature of the substance (E2>E1→N2<N1). There are a series of methods that can lead to N2>N1, when an inversion of population happens between the two energetic levels. If in this case an electromagnetic radiation is applied to the substance (called active medium) with the energy hν=E2-E1, then it can produce stimulated radiation. Besides the incident photons we obtain others with the same energy and in phase with the initial ones. In this way the energetic balance shows that we can obtain an amplification of incident radiation. The described phenomenon is called LASER (Light Amplification by Stimulated Emission of Radiation).

In nature light is essential. For example during photosynthesis the ambient light is converted in chemical energy mediated by chlorophyll present in live organisms such as live plants, algae and certain bacteria. In the virtual mode, all the available energy used to sustain life is created by photosynthesis (Ardelean, Mohan, & Mihail, 2005).

The chemical equation for this process is as follows:

$$CO_2 + 2H_2A + low \quad energy = \left(CH_2\right) + H_2O + A_2 \qquad (11)$$

The H_2A formula represents a compound that can be oxidized and generate electrons; CH_2 is the general formula of assimilated hydrocarbons by the growing organisms. In the wide majority of photosynthetic organisms (especially on plants and algae), the H_2A formula is composed by water and O_2. On some photosynthetic bacteria, H_2A represents Sulphydric acid (H_2S).

The process of photosynthesis that involves water is the most known one. The first step is the light absorption mediated by pigments. Chlorophyll captures the red and violet light spectrum and converts it into chemical energy. Photosynthesis comprises of two steps: a series of chemical reactions dependent of light only, and a series of processes dependent of temperature only. The former is not dependent of temperature and the later is not dependent of light. By increasing the light intensity we can increase the rate of chemical reaction and by increasing the temperature we can increase the rate of second photosynthesis step. Both rate increases are saturated at a certain point (Ardelean et al., 2005).

In the photosynthesis process the light energy is captured by photo system II, and the energized electrons are transmitted to an electron receiver. They are replaced in photo system II by the electrons presents in the water molecule, and later the oxygen is released. Energized electrons are then transported towards the photo system I. In this process is generated a very energetic substance. It is called adenosine triphosphate (NAPDH2).

This described how the light interacts with certain systems and the role of chlorophyll in this process.

Now we move on to describe how the light is perceived by humans (Vlada at al., 2010). Of course we use our eyes to “sense” light. With its presence, the surrounding objects image is formed on the retina. To reach the retina, light is traveling through transparent medium like cornea, macula, crystalline and vitreous corpus (see figure no. 2) (Partin & Logofatu, 2009).

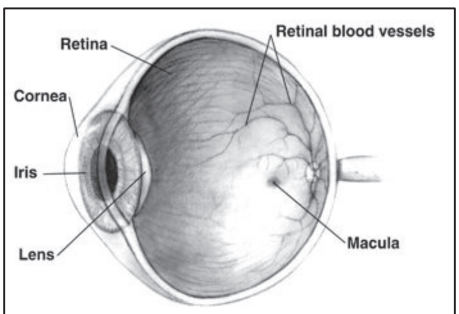

Figure 2. Structure of the Human’s eye

Retina contains photo receptor cells that transform the light, by using chemical reactions, into a nervous impulse transmitted to the brain. These cells become excited under the light conditions. It follows the appearance of a hyper polarization by increasing the number of negative charges inside the photoreceptor cells. In the dark environment the sodium ions create an electrical circuit between the internal and external segments of the photo receptor cell. Initially, on the retina, the real object appears inverted and diminished. Finally, the object image is analyzed by brain and becomes stigmatic image (Partin & Logofatu, 2009).

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3. Experimental device

To understand the light phenomena, as well as matter structure, the researchers use laser on large scale. The "Laser-induced fluorescence" (LIF) is a spectroscopic method used for studying structure of the molecules, detection of selective species and flow visualization and as well as various measurements (Bunget, 1988).

The species to be examined are excited with a laser beam. The wavelength is often selected to be the one at which the species has its largest cross section. The excited species will be, after some time that usually is in the order of few nanoseconds to microseconds, de-excited and emit light at a wavelength larger than the excitation wavelength. This wavelength can be measured and analyzed. We can differentiate between two different kinds of spectra: disperse spectra and excitation spectra.

The disperse spectra is performed with a fixed lasing wavelength, as above and the fluorescence spectrum is analyzed. Excitation scans on the other hand collect fluorescent light at a fixed emission wavelength or range of wavelengths. In this case the lasing wavelength is changed. LIF is useful in the study of the electronic structure of molecules and their interactions. The scheme of experimental device can see in figure no. 3.

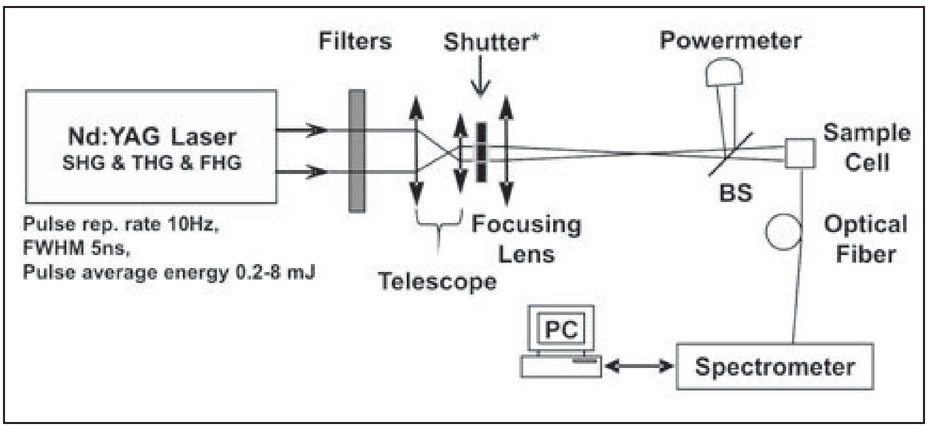

Figure 3. The scheme of experimental device at LIF

4. Conclusions

The study of light interested humans in old times and is the subject of interdisciplinary research today. The matter interacts with light and provides a wealth of information that leads to improvements in the human knowledge.

Light as notional and phenomenological content, is considered the common denominator of a set of contents in different areas which co articulate to form a whole picture (Vlada at al., 2010).

Through the integrated treatment of the concepts and natural phenomena we created a new synthesis that keeps the specific realities of the curriculum school subjects (Cucos, 2006).

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